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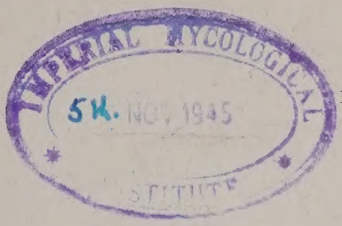

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DISEASES OF SUGAR BEETS IN CROP ROTATIONS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA FROM 1936 TO 1941

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Diseases of Sugar Beets in Crop Rotations at the Huntley Branch Station, Huntley, Montana from 1936 to 1941

M. M. Afanasiev and H. E. Morris[1]

In 1912, a series of crop rotation experiments was undertaken at the Huntley Branch Station, four miles northeast of Huntley, Montana, for the purpose of ascertaining the crops, treatments and sequences most likely to maintain the productivity of the soil and yield satisfactory crop returns.

The yield of sugar beets in the rotations was maintained generally at a fairly high level until 1927, but decreased rapidly in the unmanured plots in the following years. The decline occurred first in the 4-year rotations, then in some of the other rotations, and in 1930 it was very noticeable in a 6-year rotation (rotation 60). The decreasing yield was most apparent in the beet crop, as the yields of most of the other crops remained at a fairly high level.

The annual yields and appearance of the sugar beets indicated that the supply of available nutrients, especially phosphorus and nitrogen, had been too depleted for the profitable growing of sugar beets. Malnutrition predisposes sugar beet seedlings to attacks by parasitic organisms in the soil; therefore, the disease problem was also becoming important (3)[2].

In 1936, the Botany and Bacteriology Department of the Agricultural Experiment Station of Montana State College began an intensive investigation in twenty rotations[3] which contained sugar beets to determine the cause of the decreasing yields of sugar beets. Fourteen of these rotations were begun in 1912; five in 1916; and the "maximum production" experiment in 1926 (table 1).

The objectives of this investigation were to determine the relationship of the crops, their treatments, and sequences in the various rotations to the diseases of sugar beets and to make recommendations for their control.

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[2]Numbers in parentheses refer to Literature Cited. p. 19.

[3]The authors are indebted to Mr. Dan Hansen, Superintendent of the Huntley Branch Station and Mr. Stephen H. Hastings, Principal Agronomist, Bureau of Plant Industry, U. S. D. A., for their interest in this study and for furnishing assistance and facilities during this investigation.

The soil where these experiments were conducted consists of a heavy clay loam relatively productive and representative of beet-producing areas in Montana east of the Continental Divide. The cultural methods followed were in keeping with the practices generally followed in the area and believed to be the most desirable to bring about the best results. The season of 1935 completed the twenty-fourth year since these rotations were established.

Various reports of these rotations recording and discussing the results have been published (4, 5, 6, 7). These reports emphasized the effect of rotation, sequence, manure and alfalfa on the yields of sugar beets with little attention given to diseases or soil deficiencies such as nitrogen and phosphorus.

EXPERIMENTAL PROCEDURE

During this investigation sugar beets were grown once on each plot of the 6-year rotations, and more than once on the same plot of the shorter rotations.

The principal phases of the study included:

1. The nature and prevalence of diseases of sugar beets.
2. The effect of preceding and other crops in rotations and their treatments on the type and amount of different diseases of sugar beets.
3. The correlation of the amount of disease with the stand, yield, and top-to-root proportion.

Sugar beet diseases were studied in twenty rotations (table 1) using the following procedure:

1. Sugar beet seedlings in large numbers were examined for disease when plants were in about the six-leaf stage when seedling diseases usually are at their maximum intensity. Pre-emergence diseases usually were responsible for only a slight loss.
2. The stand of beets in every alternate row in all rotations was counted several times during each growing period. A perfect stand of sugar beets per acre was considered to be 26136, i. e., rows 20 inches apart and beets spaced 12 inches apart in the rows. At the same time records were made on all beets having symptoms of phosphorus deficiency, sugar beet yellows and other diseases.
3. At harvest time a sample of 50 beets was dug from each rotation plot and data were obtained regarding the proportion of tops to roots.
4. The yield data of all plots were taken from the records of the Huntley Branch Station.

TABLE 1. SUGAR BEET ROTATION, CROP SEQUENCE AND SOIL TREATMENTS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA

No.	Date Begun	Rotations
2	1912	Sugar beets.
2b(a)	1912	Sugar beets (manure* each year).
2c(b)	1916	Sugar beets continuous to 1927 (manure alternate years).
20	1912	Sugar beets, potatoes.
21	1912	**Sugar beets (manure), potatoes.
22	1912	Sugar beets, oats.
23	1912	Sugar beets, oats (manure).
30	1912	Sugar beets, potatoes, oats.
31	1912	Sugar beets, potatoes, oats (manure).
32	1912	Sugar beets, corn, oats.
34	1916	Sugar beets, oats, potatoes.
35	1916	Sugar beets, oats (manure), potatoes.
40	1912	Sugar beets, alfalfa, potatoes, alfalfa.
42	1912	Sugar beets, alfalfa, alfalfa, oats.
46	1916	Sugar beets, oats, alfalfa, alfalfa.
60	1912	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats.
61	1912	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats (manure).
63	1912	Sugar beets, alfalfa, alfalfa, alfalfa, (hogged 3rd year), corn (hogged), Oats, (since 1937) (flax in 1936).
64	1916	Sugar beets, oats, alfalfa, alfalfa, alfalfa, potatoes.
Max.(c)		.A. Alfalfa, alfalfa, alfalfa, potatoes, sugar beets, barley.
Prod.	1926	B. Alfalfa, alfalfa, corn, oats, beans.

(a) Rotation started in 1912 as continuous wheat, discontinued in 1926. Fallowed in 1927. Planted to beets in 1928 and manured yearly.

(b) Rotation 1916 to 1927 continuous beets. Since 1927 manured alternate years (1927, 1929, etc.).

(c) Two plots alfalfa plowed each year. Manure (16T) applied to all plots planted to cultivated crops and alfalfa. Ammonium sulphate to potatoes 1928-1932. Treble superphosphate to beets since 1930, also to alfalfa and grain crops occasionally.

*Manure applied at the rate of 12 tons per acre.

**Sugar beets (manure) indicates that the manure was applied to the land after harvesting the sugar beets as a soil amendment for the succeeding crop.

EXPERIMENTAL RESULTS

During the first season (1936) it was found that the most serious parasitic and nutritional diseases of sugar beets which occurred were:

1. *Parasitic diseases.*
   A. Seedling disease or so-called black root (3).
   B. Sugar beet yellows or fusarium wilt, caused by *Fusarium conglutinans* Wr. v. betae Stewart (8).
2. *Nutritional diseases.*
   A. Phosphorus deficiency.
   B. Nitrogen deficiency.

Preliminary reports (1) concerning the occurrence of seedling

disease, phosphorus deficiency and sugar beet yellows in these rotations and also a description of the symptoms and nature of phosphorus deficiency (2) of sugar beets have been previously published.

Besides these important diseases or deficiencies there were also present other diseases of minor importance such as brown rot of sugar beets, caused by *Rhizoctonia*, and other root rots caused by other soil organisms. To a very small extent leaf spot diseases caused by *Cercospora* and *Phoma* were also present. Curly top disease of sugar beets which was sometimes very serious was largely eliminated by planting curly top-resistant selections of beets.

The percentages of seedling disease, phosphorus deficiency, sugar beet yellows, stand, tops, roots, and the yield in tons of sugar beets in the 20 rotations for the period 1936 to 1941 are given in Appendix tables I-VII. The averages for the 6-year period are shown in figures 1-3.

In presenting the data, seedling disease, sugar beet yellows and phosphorus deficiency of sugar beets will be emphasized. A comparison then can be made between the amounts of diseases, the yield, the stand, and the top-to-root percentage of sugar beets in each rotation. Also, the effect of the other crops and the treatments involved in the rotations on the development of the diseases and how they affect the yield and stand of beets can be compared by studying single rotations and their related groups. The yearly amounts of these different factors indicate some variation, but the trends remained the same with but few exceptions.

Records of phosphorus deficiency and sugar beet yellows were not taken in 1936. Top-to-root proportions were not taken in 1941, due to an early frost with heavy snowfall which practically ruined all leaves.

CONTINUOUS CROPPING TO BEETS

Sugar beets were grown continuously in rotation 2 (check), 2b (manure), and 2c (manure alternate years). During the 30-year period, crops or treatments or both were changed in rotations 2b and 2c (table 1). These rotations, however, were continuous, so that the accumulative effect of the crops and treatments was sufficient to compare them with rotation 2. The percentages of seedling disease of sugar beets in these rotations varied between 32.5 and 44.1 (figure 1). The highest amount for the 6-year period was in rotation 2c, and the lowest in rotation 2b. The sugar beets in rotation 2 showed more phosphorus deficiency and sugar beet yellows than those in rotations 2b or 2c (figure 1). The yields and stands of sugar beets were highest in rotation 2b, and lowest in rotation 2 (figure 2). The percentage of tops to roots of sugar beets in these

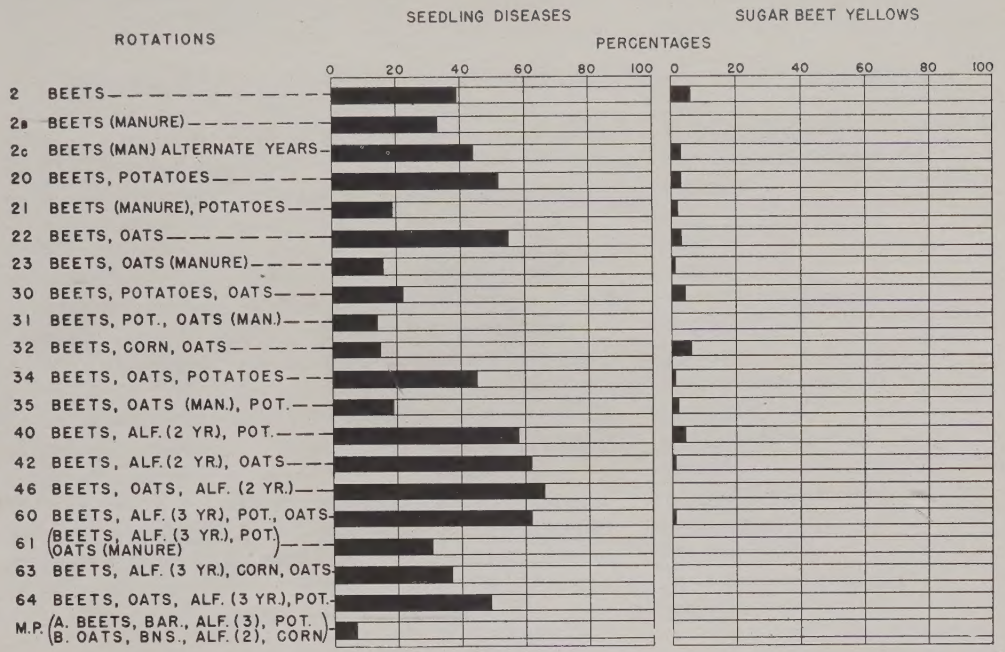
ROTATIONS
SEEDLING DISEASES
SUGAR BEET YELLOWS
PERCENTAGES
0 20 40 60 80 100
0 20 40 60 80 100
2 BEETS
2a BEETS (MANURE)
2c BEETS (MAN) ALTERNATE YEARS
20 BEETS, POTATOES
21 BEETS (MANURE), POTATOES
22 BEETS, OATS
23 BEETS, OATS (MANURE)
30 BEETS, POTATOES, OATS
31 BEETS, POT., OATS (MAN.)
32 BEETS, CORN, OATS
34 BEETS, OATS, POTATOES
35 BEETS, OATS (MAN.), POT.
40 BEETS, ALF. (2 YR), POT.
42 BEETS, ALF. (2 YR), OATS
46 BEETS, OATS, ALF. (2 YR.)
60 BEETS, ALF. (3 YR), POT., OATS
61 (BEETS, ALF. (3 YR.), POT.) OATS (MANURE)
63 BEETS, ALF. (3 YR.), CORN, OATS
64 BEETS, OATS, ALF. (3 YR.), POT.
M.P. (A. BEETS, BAR., ALF. (3), POT. B. OATS, BNS., ALF. (2), CORN)

Figure 1. Percentages of seedling disease and sugar beet yellows of sugar beets in rotations at Huntley Branch Station, Montana. Seedling diseases, averages for years 1936 to 1941, inclusive. Sugar beet yellows, average for years 1937 to 1941, inclusive.

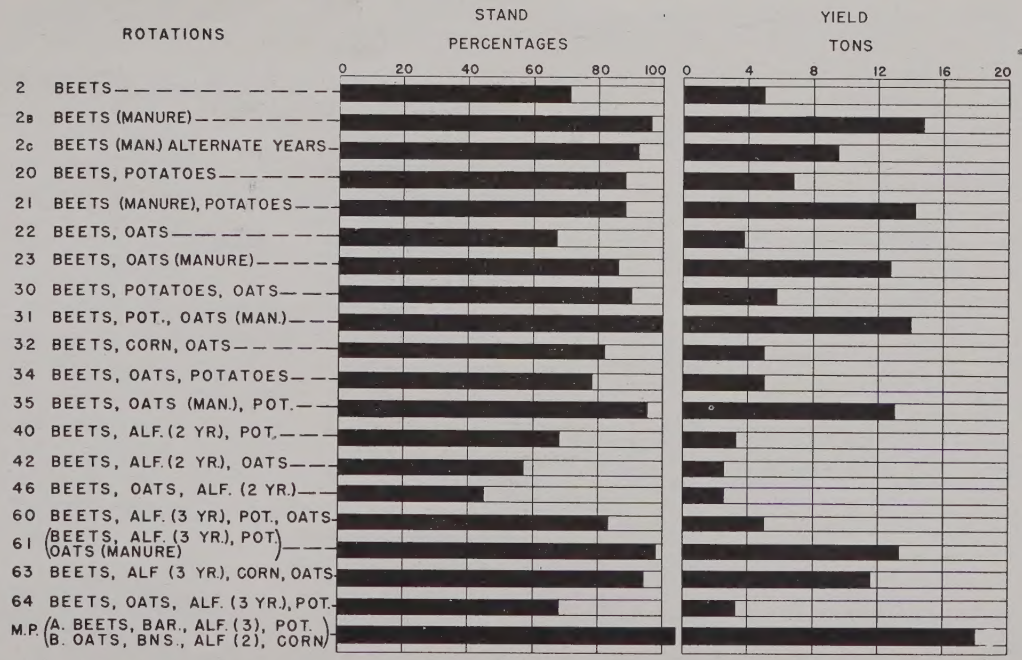
ROTATIONS
STAND
PERCENTAGES
0 20 40 60 80 100
YIELD
TONS
0 4 8 12 16 20
2 BEETS
2B BEETS (MANURE)
2C BEETS (MAN.) ALTERNATE YEARS
20 BEETS, POTATOES
21 BEETS (MANURE), POTATOES
22 BEETS, OATS
23 BEETS, OATS (MANURE)
30 BEETS, POTATOES, OATS
31 BEETS, POT., OATS (MAN.)
32 BEETS, CORN, OATS
34 BEETS, OATS, POTATOES
35 BEETS, OATS (MAN.), POT.
40 BEETS, ALF. (2 YR), POT.
42 BEETS, ALF. (2 YR), OATS
46 BEETS, OATS, ALF. (2 YR.)
60 BEETS, ALF. (3 YR), POT., OATS
61 (BEETS, ALF. (3 YR.), POT.) OATS (MANURE)
63 BEETS, ALF (3 YR.), CORN, OATS
64 BEETS, OATS, ALF. (3 YR.), POT.
M.P. (A. BEETS, BAR., ALF. (3), POT. B. OATS, BNS., ALF (2), CORN)

Figure 2. Percentages of theoretical stand (26136) and yield (tons) of sugar beets in rotations at the Huntley Branch Station, Montana.
Average for years 1936 to 1941, inclusive.

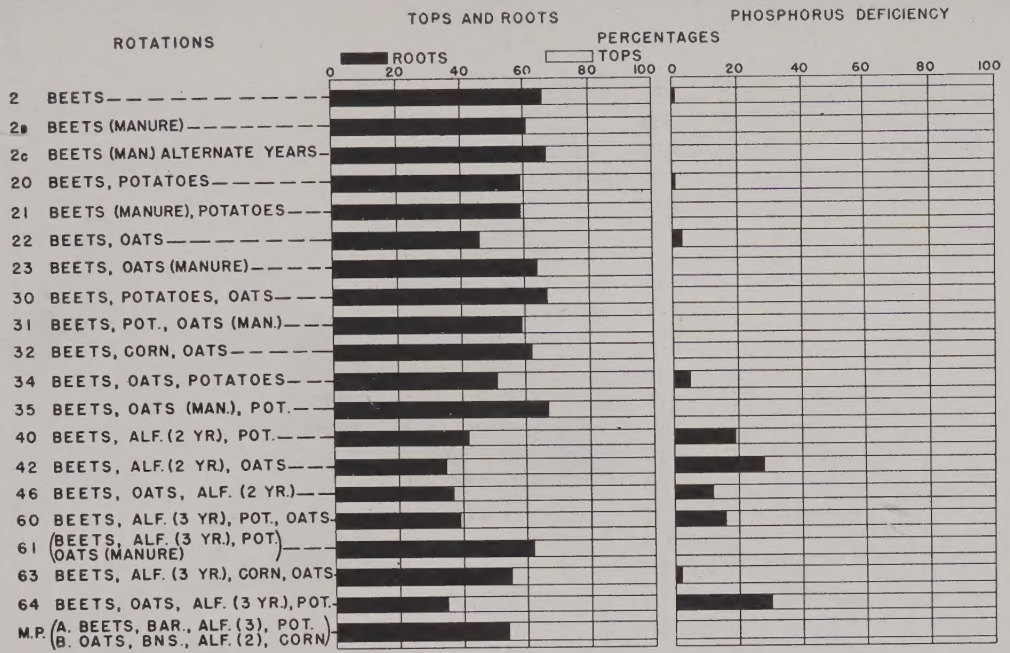
TOPS AND ROOTS
PHOSPHORUS DEFICIENCY
ROTATIONS
PERCENTAGES
ROOTS
TOPS
0 20 40 60 80 100
0 20 40 60 80 100
2 BEETS
2a BEETS (MANURE)
2c BEETS (MAN) ALTERNATE YEARS
20 BEETS, POTATOES
21 BEETS (MANURE), POTATOES
22 BEETS, OATS
23 BEETS, OATS (MANURE)
30 BEETS, POTATOES, OATS
31 BEETS, POT., OATS (MAN.)
32 BEETS, CORN, OATS
34 BEETS, OATS, POTATOES
35 BEETS, OATS (MAN.), POT.
40 BEETS, ALF. (2 YR), POT.
42 BEETS, ALF. (2 YR), OATS
46 BEETS, OATS, ALF. (2 YR.)
60 BEETS, ALF. (3 YR), POT., OATS
61 (BEETS, ALF. (3 YR.), POT. OATS (MANURE))
63 BEETS, ALF. (3 YR.), CORN, OATS
64 BEETS, OATS, ALF. (3 YR.), POT.
M.P. (A. BEETS, BAR., ALF. (3), POT. B. OATS, BNS., ALF. (2), CORN)

Figure 3. Percentages of tops and roots and phosphorus deficiency of sugar beets in rotations at the Huntley Branch Station, Montana.

Tops and roots, average for years 1936 to 1940, inclusive. Phosphorus deficiency, average for years 1937 to 1941, inclusive.

three rotations approximated 35.0 to 40.0 per cent for tops and 60.0 to 65.0 per cent for roots, which is considered to be about normal. This indicated that the supply of available nitrogen and phosphorus was proportional for the balanced nutrition of sugar beets in these rotations, but the total amount of these substances, judging by the yield, was undoubtedly very low in rotation 2. more or less sufficient in 2b, and intermediate in rotation 2c.

Although the amounts of seedling disease of sugar beets in these rotations were approximately the same, the stand and the yield of beets in rotation 2 was considerably lower than in the other two rotations (figure 2). This could be explained on the basis that in soils better supplied with nutrients (rotations 2b and 2c) diseased beets have more chance to recover and produce better yields than in a poor, exhausted soil. These results also show that continuous cropping of beets in the same ground either with or without manure has a tendency to increase seedling disease of sugar beets.

The prevalence of phosphorus deficiency and sugar beet yellows was considerably higher in the sugar beets in unmanured rotation 2 than in rotation 2b which was manured every year (figure 3). The amounts of these diseases in rotation 2c, manured alternate years, were intermediate. These results indicate that the occurrence of phosphorus deficiency and sugar beet yellows could be negatively correlated with the fertility of the soil.

TWO-YEAR ROTATIONS

Rotations 20 and 21 were similar, consisting of potatoes and sugar beets, except that in rotation 21 manure was applied to the potatoes. Beets in rotation 20 had a high amount of seedling disease (52.3 per cent) and in rotation 21 (manure) a rather small amount (19.1 per cent). Beets in both of these rotations had traces of phosphorus deficiency and a slight amount of sugar beet yellows. The average stand of beets was about the same, but the yield was more than twice as much for rotation 21 (manure) than for rotation 20 (no manure).

Another set of 2-year rotations was 22 and 23 which also had identical crops consisting of oats and sugar beets, except that rotation 23 had manure applied to the sugar beets. Sugar beets in rotation 22 had high percentages of seedling disease (54.6 per cent), and a slight amount of phosphorus deficiency and sugar beet yellows, while those in rotation 23 were lower in percentages of seedling disease (16.4 per cent), phosphorus deficiency and sugar beet yellows but had a relatively high stand and yield.

The top-to-root percentages of sugar beets were about normal in rotations 20, 21, and 23, but in rotation 22 the tops were un-

proportionally heavier than the roots. Judging by the yield the nutrients in the soil of rotations 21 and 23 were available in sufficient amounts, but they were somewhat depleted in the soils of rotations 20 and 22. In rotation 22, as judged by the top-to-root percentages and by the amount of phosphorus deficency, phosphorus was more depleted than nitrogen (figures 1-3).

THREE-YEAR ROTATIONS

Rotations 30 and 31 were similar, consisting of potatoes, oats and sugar beets, except that in rotation 31 manure was applied to the sugar beets. Seedling disease of sugar beets was not serious in these rotations, although the unmanured rotation had somewhat more than the manured rotation (22.4 per cent for rotation 30 and 13.8 per cent for rotation 31). The beets in these rotations had slight symtoms of phosphorus deficiency. There was a small amount of sugar beet yellows in rotation 30 and only traces of it in rotation 31. The stand of beets was very good in rotation 31 and fairly good in rotation 30. The yield of beets in manured rotation 31 was more than twice that of the unmanured rotation 30.

Sugar beets in rotation 32, consisting of corn, oats and sugar beets had a low amount of seedling disease (14.7 per cent), traces of phosphorus deficiency, and more sugar beet yellows than in any other rotation (6.08 per cent). The stand of beets in this rotation was fair, but the yield was low.

The other 3-year rotations were 34 and 35 which were similar to rotations 30 and 31, consisting of identical crops, namely, potatoes, sugar beets and oats, but in a different sequence. Manure was applied to the potatoes in rotation 35. Rotation 34 had a considerable amount of sugar beet seedling disease (44.8 per cent), a slight degree of phosphorus deficiency and a small amount of sugar beet yellows. Sugar beets in rotation 35 had a slight amount of seedling disease (19.1 per cent) and sugar beet yellows and traces of phosphorus deficiency. The stand of beets was fair in rotation 34 and very good in rotation 35. The yield of beets in rotation 34 was low and in rotation 35, comparatively high.

The beets of 3-year rotations 30, 31, 32 and 35 had normal top-to-root percentages, but the beets of rotation 34 had heavier tops as compared to the roots. Judging by the yield, the nutrients in the soil of manured rotations 31 and 35 were available in amounts about sufficient, but the nutrients of unmanured rotations 30, 32 and 34 were somewhat depleted, and in addition they were unbalanced in the soil of rotation 34 as is indicated by the top-to-root percentages and the occurrence of phosphorus deficiency in the beets (figures 1-3).

FOUR-YEAR ROTATIONS

In the 4-year rotations 40, 42 and 46, are found different crops and a different sequence of the same crops. Rotation 40 consists of potatoes, sugar beets and 2 years of alfalfa; rotation 42, oats, sugar beets and 2 years of alfalfa and rotation 46, sugar beets, oats, and 2 years of alfalfa. In rotation 46, sugar beets were planted immediately after alfalfa. No manure was applied to any of these rotations. The beets in these rotations had high amounts of seedling disease (a variation of between 58.0 and 65.7 per cent) considerable amounts of phosphorus deficiency (a variation of between 11.69 and 28.11 per cent), traces of sugar beet yellows and low stands and poor yields. It was often necessary to replant the beets in rotation 46 because of the severity of seedling disease (figures 1-3).

In these 4-year rotations the tops of beets showed a more intensive development than the roots, which indicated that there was an unbalanced nutrition with considerable excess of nitrogen over phosphorus. This situation could be expected because the sugar beets in this group of rotations were planted either directly after 2 years of alfalfa or with an intermediate crop between alfalfa and beets. It is known that alfalfa is a heavy feeder on phosphorus, so after cropping for 2 years it may be assumed that the soil was depleted in available phosphorus. At the same time, alfalfa, as compared to non-leguminous crops, largely maintains the nitrogen content of the soil, which tends to unbalance the ratio between nitrogen and phosphorus.

SIX-YEAR ROTATIONS

Rotations 60 and 61 were similar, consisting of potatoes, oats, sugar beets and 3 years of alfalfa, the only difference being that in rotation 61 manure was applied to the beets. Sugar beets grown in rotation 60 had a high amount of seedling disease (61.8 per cent), a considerable amount of phosphorus deficiency, traces of sugar beet yellows, a fairly high stand and low yield. Beets grown in rotation 61 had a moderate amount of seedling disease (31.2 per cent), traces of phosphorus deficiency and sugar beet yellows, a high stand and comparatively high yield.

Rotation 63, also a 6-year rotation, consisted of corn (hogged off), flax, sugar beets and 3 years of alfalfa (the last crop of alfalfa was hogged off) until 1937, when oats were substituted for flax. Beets grown in this rotation had a moderate amount of seedling disease (36.8 per cent), a slight amount of phosphorus deficiency, and traces of sugar beet yellows. The stand of the beets was high and the yield also comparatively high.

Rotation 64 consisted of potatoes, sugar beets, oats, and 3 years of alfalfa and resembled very closely rotations 60 and 61 except that sugar beets were planted after potatoes while in rotation 60 and 61 they were planted after oats. The beets grown in this rotation had a high amount of seedling disease (49.0 per cent), a considerable amount of phosphorus deficiency (30.3 per cent), traces of sugar beet yellows, a low stand and yield.

In the 6-year rotations which had 3 years of alfalfa, the percentages of tops to roots of sugar beets in unmanured rotations 60 and 64 resembled those of the 4-year rotations, which indicated an extreme deficiency of their soils in phosphorus as compared to nitrogen. Sugar beets in rotations 61 and 63 (manured) showed about a normal top-to-root ratio. Manure apparently had a beneficial effect in controlling soil deficiencies and in maintaining the yield of sugar beets in the rotations (figures 1-3).

MAXIMUM CROP-PRODUCTION ROTATION

Sugar beets in the maximum crop-production experiment (MP), where soil amendments are adjusted to the requirements of the crop, were included in this study to illustrate the difference between it and a rotation where soil treatments are identical each year and have little or no relationship to the requirements of the crop.

Sugar beets in the maximum crop-production rotation, as compared to those in other rotations, always have the lowest amounts of all diseases, the highest stands and yields, and about a normal ratio of tops to roots. In some years the top-to-root ratio indicates a possible deficiency of phosphorus in the soil (figures 1-3).

SUGAR BEET SEEDLING DISEASE

Although in the types of sugar beet seedling diseases occurring at the Huntley Branch Station, many of the diseased seedlings recovered, usually there was a high mortality. Damage to the crop therefore resulted not only from a reduced stand but also from retarded growth of the recovered seedlings.

The data (figure 1) indicate that sugar beets grown in rotations MP, 31, 32, 23, 21, 35 and 30 had the smallest amounts of seedling disease, namely, between 7.4 per cent (rotation MP) and 22.4 per cent (rotation 30). These rotations, except rotations 30 and 32, belong to the group in which manure was applied to the soil. Greater amounts of seedling disease occurred in the unmanured 2-year rotations, and in the unmanured 4- and 6-year rotations with alfalfa. Sugar beets in rotation 46 had the highest amount of seedling disease of all the rotations (65.7 per cent). Beets in some of the manured rotations sometimes had a considerable

amount of seedling disease, but due to their vigor many seedlings recovered and produced good marketable beets. In the poorer plots many of the infected seedlings succumbed to the disease or else produced small beets. This becomes very evident when the amounts of seedling disease of sugar beets in similar manured and unmanured rotations are compared, i. e., 20 and 21, 22 and 23, 34 and 35, etc. The difference in the amounts of seedling disease of the beets in manured and unmanured rotations with alfalfa is not as pronounced as in those without alfalfa, because all rotations with alfalfa had rather high amounts of seedling disease. The only exception was the "maximum production" rotation, which had the least amount of disease.

PHOSPHORUS DEFICIENCY OF SUGAR BEETS

The data (figure 3) indicate that phosphorus deficiency was pronounced in only five rotations, 40, 42, 46, 60, and 64. The beets showing phosphorus deficiency in these rotations varied between 11.69 per cent (rotation 46) and 30.03 per cent (rotation 64). Beets in the maximum production rotation were usually free of phosphorus deficiency. Beets in rotations 2, 20, 22, 34 and 63 generally showed a small amount of phoshorus deficiency.

The percentages of phosphorus-deficient beets were based on beets which had definite symptoms. If beets showing traces to very slight amounts of phosphorus deficiency had been included, the percentages would have been much higher.

Sugar beets grown in the rotations to which manure was applied had less phosphorus deficiency than those in identical non-manured rotations. Apparently the phosphorus added to the soil with the manure was the controlling factor. This is especially evident when manured and non-manured rotations with alfalfa are compared.

SUGAR BEET YELLOWS (FUSARIUM WILT) OF SUGAR BEETS

Sugar beets grown in the majority of the rotations (figure 1) had a trace or more of this disease. The highest percentages of this disease occurred in rotation 2 (5.63 per cent) and rotation 32 (6.08 per cent) and the lowest in the maximum production rotation (0.04 per cent). In general, sugar beets grown in rotations including alfalfa had the least disease, and those grown in the 1-, 2-, or 3-year rotations the most.

DISCUSSION

Seedling disease of sugar beets in the rotations at the Huntley Branch Station affected the crop by causing the death of many seedlings, which reduced the stand, and by a retarded growth of

recovered beets. Beets in some of the manured rotations sometimes had a considerable amount of seedling disease, but because of their vigor more of the plants recovered and produced about normal beets than those in the rotations without manure. Manure may not only supply some available plant food to the beets but it supports the development of saprophytic soil organisms which, through competition, may reduce the number of parasitic organisms in the soil.

Beets planted in unmanured rotations with alfalfa had a very high amount of seedling disease and a considerable degree of phosphorus deficiency. In explaining this fact it is necessary to consider the method generally used in preparing the alfalfa ground for the next crop. After removing the third alfalfa crop in the latter part of September, the alfalfa stubble is crowned and after 3 to 4 weeks, as soon as the crowns have dried out, the field is plowed. Under conditions of dry weather in the fall and hard frost in the winter, most of the alfalfa crowns and roots remain in the soil without much decomposition, a situation which makes it very difficult to prepare a good seed bed. The main decomposition of alfalfa residue begins only with moist, warm spring weather which closely coincides with the germination and growth of sugar beet seedlings. Fungi are the first soil agents attacking plant materials, thus paving the road for bacteria and actinomyces. Most of the seedling disease of sugar beets is caused by fungi, and conditions favorable for the optimal development of some fungi will also favor the development of these pathogenic organisms. It appears, therefore, that alfalfa ground should be plowed preferably in midsummer and then irrigated to favor decomposition of alfalfa residue during the current season. The soils of these rotations in which alfalfa was grown for several years are found deficient in available phosphorus and available nitrogen especially during the spring and early summer. Alfalfa is a very heavy feeder on phosphorus so, after cropping for several years, the soil is depleted in available phosphorus while at the same time the total nitrogen content of the soil is maintained. This tends to change the ratio between nitrogen and phosphorus. Although alfalfa does not decrease the total nitrogen content of the soil in these rotations, there is only a small amount of available nitrogen present in the plowed alfalfa ground early in the spring, as most of the nitrogen at that time is present in the form of organic compounds in the alfalfa residue, the decomposition of which is only beginning. Young beets require considerable nitrogen in their early stages of development and a deficiency of available nitrogen in the soil makes the seedlings grow slowly and become susceptible to diseases. However, later on in the season, when nitrogen from the alfalfa residue becomes available, the beets which survive seedling disease have proportionally more nitrogen than

phosphorus for their nutrition. With the beginning of intensive growth of the root, usually in July, the phosphorus requirement of the beets increases; they suffer from lack of this element and begin to show symptoms of phosphorus deficency. This is due to phosphorus deficiency in the soil and especially to an unbalanced ratio between the very low amount of available phosphorus and a surplus of available nitrogen. As evidence of this the beets in the unmanured rotations with alfalfa always have more pronounced symptoms of phosphorus deficiency than those in continuous or in 2- or 3-year rotations which have a very low amount of available phosphorus and nitrogen in the soil. A further proof of this unbalanced nutrition of sugar beets in the rotations including alfalfa was the unfavorable ratio of beet tops to roots. It is believed that the ratio of tops to roots is a very important indicator of the fertility level of the soil in which beets are grown. Usually in normal soils well balanced in nutrients this ratio is 35.0 to 40.0 per cent for tops and 60.0 to 65.0 per cent for roots at harvest time, providing the season is long enough for beets to reach a normal balance in their growth. An excess of nitrogen over phosphorus will support a greater development of tops as compared with roots, and an excess of phosphorus over nitrogen will support a greater develoment of roots as compared with the tops. Therefore the deficiencies of phosphorus and nitrogen in the soils of these rotations are indicated by the ratio of tops to roots of the sugar beets.

Phosphorus deficiency of beets was more pronounced in 4- and 6-year rotations with alfalfa. However, nitrogen deficiency of beets was more pronounced in short, unmanured 1-, 2-, and 3-year rotations, which by the middle of the summer usually could be recognized by their yellow color and stunted growth.

Sugar beets in rotations with alfalfa and manure had very little phosphorus deficiency. Manure adds a certain amount of phosphorus to the soil and supports the development of microorganisms which may be responsible for rendering the phosphorus in the soil more available to the sugar beets.

Sugar beet yellows occurred mostly in 1-, 2-, and 3-year rotations. Rotations 30, 32 and 2 without manure always had considerable disease, while the 4- and 6-year rotations were practically free. There is indication that an application of manure possibly had some effect in reducing the amount of yellows in sugar beets.

It was impossible to predict all the complications which would arise from a gradual depletion of available nutrients in the soil when these rotations were started 30 years ago. In general, the results indicate that the severity of practically all the diseases of

sugar beets occurring in these rotations, with the possible exception of sugar beet yellows, is basically due to depletion of the available nutrients in the soil. Similar results were obtained in investigation on the control of seedling disease of sugar beets (3). These facts become especially evident when the nineteen rotations are compared with the maximum crop-production experiment, which was conducted on similar soil and under similar environmental conditions except that it was well supplied with manure and inorganic fertilizers. Beets planted in the maximum crop-production rotation always had a minimum of diseases, excellent stands and the highest yields as compared with the beets in the other rotations.

SUMMARY

1. Diseases of sugar beets were investigated in the twenty rotations (started in 1912 or 1916) at the Huntley Branch Station during the period 1936 to 1941.

2. Seedling disease of sugar beets was high in all unmanured rotations except rotations 30 and 32 which had somewhat different soil from the rest of the rotations. Sugar beets grown in manured rotations had a relatively small amount of seedling disease.

3. Sugar beets planted in unmanured rotations, which had several years of alfalfa, had a considerable amount of phosphorus deficiency while similar rotations with application of manure were practically free of phosphorus deficiency.

4. Sugar beet yellows was present in the beets in the 1-, 2-, and 3-year rotations and practically absent in the 4- and 6-year rotations.

5. Sugar beets grown in 1-, 2-, and 3-year rotations without an application of manure always showed signs of nitrogen deficiency by the middle of summer.

6. In general the stands and yields of the sugar beets were fairly good to excellent in manured rotation, poor in unmanured rotations and very poor in unmanured rotations with alfalfa.

7. Top-to-root ratios of the beets grown in these rotations were about normal with the exception of rotations 20, 34, 40, 42, 46, 60 and 64 where the tops were considerably heavier than the roots. This fact indicates that available phosphorus was more depleted than nitrogen in the soils of these rotations. This is especially true in unmanured rotations with alfalfa (40, 42, 46, 60 and 64).

8. The occurrence of high amounts of seedling disease and a considerable amount of phosphorus deficiency in sugar beets mainly in the unmanured rotations indicates that the depletion of the soil is mainly responsible for the prevalence of this disease.

9. Beets planted in the maximum crop-production rotation, the soil of which was well supplied with manure and inorganic fertilizers, had a minimum of diseases, excellent stands and yields.

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APPENDIX

TABLE I. SEEDLING DISEASE OF SUGAR BEETS IN THE CROP ROTATIONS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA, 1936-1941

Rotation number	Seedling disease						
	1936	1937	1938	1939	1940	1941	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	37.7	21.6	23.9	46.1	64.3	37.4	38.5
2b	31.0	18.4	14.6	44.4	39.8	47.0	32.5
2c	44.6	35.9	20.1	82.0	41.1	41.0	44.1
20	49.5	23.7	40.0	65.1	75.8	59.6	52.3
21	42.9	11.8	13.3	12.2	16.5	17.8	19.1
22	37.9	36.4	39.6	77.9	76.0	59.7	54.6
23	26.6	14.0	4.1	13.7	13.7	26.0	16.4
30	60.0	5.7	25.0	16.8	14.8	11.8	22.4
31	16.0	14.7	5.8	10.2	12.5	23.7	13.8
32	15.2	10.4	7.1	23.7	18.2	13.8	14.7
34	50.4	16.1	23.7	86.0	66.5	26.0	44.8
35	41.8	8.4	6.2	32.4	21.8	4.2	19.1
40	51.1	33.3	38.0	72.5	68.2	84.7	58.0
42	46.2	59.3	41.4	74.4	75.5	76.0	62.1
46	72.4	76.8	28.6	76.3	72.8	67.1	65.7
60	32.6	55.1	52.0	71.2	87.7	72.4	61.8
61	20.0	26.8	4.2	7.2	48.8	80.3	31.2
63	46.2	17.9	5.7	23.5	64.2	63.0	36.8
64	58.5	36.2	25.6	70.1	56.7	47.0	49.0
MP	—	19.3	3.7	2.3	7.1	4.4	7.4

TABLE II. SUGAR BEET YELLOWS OF SUGAR BEETS IN THE CROP ROTATIONS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA 1937-1941

Rotation number	Sugar beet yellows					
	1937	1938	1939	1940	1941	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	4.66	2.00	4.98	5.86	10.66	5.63
2b	0.23	0.07	0.33	0.23	0.93	0.36
2c	0.67	1.10	2.44	3.78	4.55	2.51
20	0.49	1.10	1.70	7.76	1.48	2.51
21	2.30	1.40	1.82	0.53	4.88	2.19
22	1.47	2.50	1.35	4.55	4.19	2.81
23	0.56	1.10	0.71	1.88	1.37	1.12
30	2.17	1.50	3.73	7.42	3.82	3.73
31	0.49	0.10	0.33	0.53	0.67	0.42
32	4.28	3.40	5.26	10.71	6.75	6.08
34	1.00	1.10	0.87	2.00	1.44	1.28
35	1.31	0.30	1.51	2.68	3.18	1.80
40	0.17	0.10	0.53	0.21	0.06	0.21
42	0.48	1.30	0.10	0.99	0.00	0.57
46	0.67	0.00	0.00	0.05	0.08	0.16
60	0.94	0.80	0.44	0.46	0.07	0.54
61	0.07	0.30	0.40	0.61	0.39	0.35
63	0.69	0.10	0.37	0.12	0.16	0.29
64	1.24	0.10	0.11	0.09	0.61	0.43
MP	0.04	0.10	0.00	0.00	0.06	0.04

TABLE III. STANDS OF SUGAR BEETS IN THE CROP ROTATIONS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA, 1936-1941

Rotation number	Stands of Sugar Beets*						
	1936	1937	1938	1939	1940	1941	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	77.1	70.6	61.1	78.0	69.5	68.3	70.8
2b	88.7	92.4	85.8	101.3	106.4	98.7	95.6
2c	74.6	96.0	102.6	96.3	86.6	92.8	91.5
20	89.6	81.3	91.1	91.8	91.9	82.6	88.1
21	65.6	65.8	82.4	102.7	119.2	92.2	88.0
22	65.6	66.8	76.8	61.6	60.5	72.3	67.3
23	55.7	70.6	85.8	108.2	96.9	100.8	86.3
30	58.7	91.5	101.7	103.2	93.3	89.0	89.6
31	92.1	92.7	109.6	110.9	95.3	101.2	100.3
32	77.1	74.3	80.9	97.2	81.8	81.1	82.1
34	52.9	66.7	91.9	84.8	87.0	87.1	78.4
35	71.3	95.9	94.7	109.3	96.0	102.9	95.0
40	54.4	52.5	81.0	80.9	86.5	54.7	68.3
42	40.7	48.2	71.8	61.2	55.5	63.4	56.8
46	19.3	40.1	38.5	38.4	62.4	72.5	45.2
60	92.6	78.2	85.9	76.6	80.7	85.9	83.3
61	92.6	80.5	107.8	108.2	105.8	94.2	98.2
63	85.2	83.9	101.1	98.3	100.9	94.0	93.9
64	44.8	69.8	63.2	84.1	83.1	63.7	68.1
MP	86.7	86.4	111.9	115.1	117.1	103.5	103.5

*Based on the theoretical stand of 26136 beets per acre.

TABLE IV. YIELDS OF SUGAR BEETS IN THE CROP ROTATIONS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA, 1936-1941

Rotation number	Yields of sugar beets						
	1936	1937	1938	1939	1940	1941	Average
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
2	4.60	6.21	5.99	3.81	4.10	5.65	5.06
2b	13.64	18.56	12.97	13.34	15.26	14.28	14.68
2c	8.84	10.34	8.33	6.25	8.52	14.53	9.47
20	4.51	7.42	7.13	4.86	6.62	9.72	6.71
21	14.80	10.43	15.60	11.77	17.25	15.45	14.22
22	2.19	4.32	4.38	2.13	2.87	6.24	3.69
23	14.59	9.70	15.13	11.86	10.67	14.61	12.76
30	8.08	5.23	5.67	5.02	4.60	5.57	5.70
31	13.72	16.34	12.40	11.27	15.40	14.35	13.91
32	4.72	6.82	6.38	3.46	3.43	4.86	4.95
34	4.11	4.40	3.95	4.71	5.74	7.60	5.09
35	11.25	13.39	12.95	8.00	14.22	17.69	12.92
40	1.45	3.31	2.59	4.38	4.09	4.10	3.32
42	2.26	2.80	2.73	1.91	1.51	4.15	2.56
46	1.67	5.34	2.67	0.99	1.64	2.43	2.46
60	5.64	6.70	4.97	3.57	4.30	5.35	5.09
61	9.87	14.61	12.58	13.05	16.07	13.79	13.32
63	9.01	17.20	10.63	10.82	8.65	12.34	11.44
64	3.37	3.16	2.02	4.99	3.85	2.35	3.29
MP	19.40	12.01	18.24	19.71	19.74	18.77	17.98

TABLE V. PERCENTAGES OF TOPS OF SUGAR BEETS IN THE CROP ROTATIONS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA 1936-1940

Rotation number	Tops					
	1936	1937	1938	1939	1940	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	29.0	32.5	33.4	35.4	41.0	34.3
2b	35.7	36.9	43.8	39.2	39.5	39.0
2c	20.5	30.1	43.5	37.5	33.9	33.1
20	40.7	35.9	41.6	44.1	40.7	40.6
21	27.9	43.1	50.0	35.6	49.4	41.2
22	59.0	44.4	48.5	61.4	56.7	54.0
23	28.0	39.8	42.0	34.4	34.5	35.7
30	23.7	35.1	31.7	31.8	41.4	32.7
31	43.8	47.5	33.8	35.6	45.9	41.3
32	45.7	36.9	32.1	30.0	45.5	38.0
34	40.9	50.5	59.0	46.2	49.1	49.1
35	28.6	25.9	36.1	32.9	39.4	32.6
40	63.3	60.3	48.7	59.7	59.4	58.3
42	62.7	57.9	57.4	68.4	78.9	65.1
46	52.3	56.3	65.0	67.4	74.3	63.1
60	51.8	55.1	63.8	61.4	70.8	60.6
61	37.7	37.1	35.5	40.8	40.6	38.3
63	48.5	41.1	49.3	42.7	45.6	45.4
64	65.3	68.1	61.1	57.3	74.5	65.3
MP	37.2	43.5	54.3	52.6	45.1	46.5

TABLE VI. PERCENTAGES OF ROOTS OF SUGAR BEETS IN THE CROP ROTATIONS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA 1936-1940

Rotation number	Roots					
	1936	1937	1938	1939	1940	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	71.0	67.5	66.6	64.6	59.0	65.7
2b	64.3	63.1	56.2	60.8	60.5	61.0
2c	79.5	69.9	56.5	62.5	66.1	66.9
20	59.3	64.1	58.4	55.9	59.3	59.4
21	72.1	56.9	50.0	64.4	50.6	58.8
22	41.0	55.6	51.5	38.6	43.3	46.0
23	72.0	60.2	58.0	65.6	65.5	64.3
30	76.3	64.9	68.3	68.2	58.6	67.3
31	56.2	52.5	66.2	64.4	54.1	58.7
32	54.3	63.1	67.9	70.0	54.5	62.0
34	59.1	49.5	41.0	53.8	50.9	50.9
35	71.4	74.1	63.9	67.1	60.6	67.4
40	36.7	39.7	51.3	40.3	40.6	41.7
42	37.3	42.1	42.6	31.6	21.1	34.9
46	47.7	43.7	35.0	32.6	25.7	36.9
60	48.2	44.9	36.2	38.6	29.2	39.4
61	62.3	62.9	64.5	59.2	59.4	61.7
63	51.5	58.9	50.7	57.3	54.4	54.6
64	34.7	31.9	38.9	42.7	25.5	34.7
MP	62.8	56.5	45.7	47.4	54.9	53.5

TABLE VII. PHOSPHORUS DEFICIENCY OF SUGAR BEETS IN THE CROP ROTATIONS AT THE HUNTLEY BRANCH STATION, HUNTLEY, MONTANA 1937-1941

Rotation number	Phosphorus deficiency					
	1937	1938	1939	1940	1941	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	2.46	1.00	0.15	0.08	0.21	0.78
2b	0.13	0.10	0.00	0.00	0.00	0.05
2c	0.32	0.20	0.30	0.53	0.10	0.29
20	2.76	1.70	0.10	0.34	0.00	0.98
21	0.81	0.00	0.00	0.00	0.00	0.16
22	5.30	4.60	0.71	5.80	0.59	3.40
23	0.51	0.10	0.00	0.00	0.30	0.18
30	0.30	0.00	0.00	0.00	0.00	0.06
31	0.10	0.00	0.00	0.00	0.00	0.02
32	0.31	0.00	0.00	0.04	0.00	0.07
34	10.65	4.00	3.38	3.95	5.07	5.41
35	1.15	0.10	0.30	0.12	0.03	0.34
40	6.69	19.10	8.85	37.40	23.50	19.11
42	15.48	13.70	3.00	62.83	45.53	28.11
46	8.74	3.40	13.54	2.11	30.65	11.69
60	4.51	6.80	11.34	39.05	17.31	15.80
61	0.99	0.50	0.03	0.00	0.32	0.37
63	0.62	0.70	1.47	5.66	1.07	1.90
64	30.94	11.10	13.21	33.30	61.59	30.03
MP	0.04	0.00	0.00	0.00	0.00	0.008